SCIENCE

FRIDAY, MARCH 24, 1899.

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson N. Y.

*THE EARLY TERTIARY VOLCANOES OF THE ABSAROKA RANGE.**

IT is, I suppose, accepted by many geologists that volcanic energy has played an important part not only in bringing about the present configuration of the Rocky Mountains, but in building up the entire northern Cordillera, stretching from the Front Range, along Colorado, Wyoming and Montana, westward to the Pacific Ocean. Over this wide area the volcanic phenomena of Tertiary time present a varied and complex mode of occurrence, offering from different points of view many problems of geological interest. These problems have been vigorously attacked both in the field and in the laboratory, and something has been accomplished tending toward their final elucidation. The literature upon the subject is already voluminous, being scattered widely through the publications of official reports, both State and National, and in the proceedings of scientific societies. While I desire to call your attention to some of these features, I do not propose to summarize the work that has already been done in this direction in a manner which is perhaps usual on occasions like the present. Neither do I wish to review the field from my own standpoint, possibly because, although much has been accomplished, such a vast amount of work remains to be done that the broad

*Address of the President before the Geological Society of Washington, February, 1899.

field seems even yet scarcely explored. I prefer, therefore, to place before you some results of personal observation in a region in which I have worked for several years and in which I have become deeply interested.

The Absaroka Range lies along the east side of the Yellowstone Park. Several of its higher peaks and its long western spurs, sloping gradually toward the Park, lie within the national reservation. During several successive summers, while engaged in geological observations in the Park, I found it necessary to penetrate beyond its boundaries into the higher encircling mountains. My first excursion into the Absarokas was undertaken in the summer of 1885, and thereafter for several years I made long and protracted journeys into this rugged and at that time almost unknown region, studying its geology, and returning each year more and more profoundly impressed by its many marvels. In the year 1893, and again in 1897, the greater part of the summer was occupied in exploration of the wild recesses of the Absarokas.

The range, which lies wholly in the State of Wyoming, stretches from the Beartooth and Snowy ranges, on the north, southward to the Owl Mountains. In width it is less sharply defined, certain outlying plateau-like areas, such as Mirror and Two-Ocean plateaus, being separated from the main body by deep valleys. Geographically they may be considered as distinct physical features. Geologically, from their mode of occurrence and the nature of the rocks, they are intimately associated with the central mass, and for the purposes of this address they may be considered as forming a part of the Absaroka Range. As thus defined, the range measures 80 miles in length by 50 miles in width, covering an area of nearly 4,000 square miles.

From one end to the other the Absarokas present a high, imposing plateau, with elevations ranging from 10,000 to over 12,000 feet above sea level. This entire mass is made up almost exclusively of Tertiary igneous rocks. Near the northern flanks Archean schists and gneisses crop out from beneath the overlying rocks. Resting upon the Archean, upturned Paleozoic limestones and sandstones having a considerable thickness come to the surface, and along the eastern borders of the range, exposed by erosion in the broader valleys, occur Cretaceous rocks. With these exceptions, the range consists of a vast accumulation of agglomerates, tuffs, lava flows and intrusive masses.

Degradation of the mass has taken place on a grand scale. Vast quantities of volcanic ejectamenta have been removed from the summit, but no reliable data exist by which the amount can be estimated even approximately. All the higher portions have been sculptured by glacial ice. Enormous amphitheatres have been carved out of the loose agglomerates, and peaks, pinnacles, and relics of great tablelands testify in some measure to the forces of erosion. The plateau is scored by a complete network of deep valleys and gorges, which dissect it in every direction and lay bare the structure of the vast volcanic pile.

Nowhere in the northern Rocky Mountains do I know grander and more rugged scenery than can be found in the Absarokas. But few natural passes lead across the mountainous tract, and these are high and difficult to scale. For years the range stood as an impassable barrier to the earlier explorers in their attempts to reach the sources of the Yellowstone from the east; and even to-day the region is seldom penetrated to its inmost recesses except by those engaged in scientific exploration of the country, by the prospector in search of precious metals, or by a few adventurous sportsmen in pursuit of the big game of the Rockies. Much of this region is covered by a dense growth of

coniferous forest, and the greater part of the forests lying east of the Yellowstone Park belong to the Yellowstone timber reserve, the first of the forest reservations set aside by proclamation of the President under the Act of Congress approved March 1, 1891.

Rightly to understand the true position of this volcanic area it is necessary to review briefly the geological history of the surrounding region before the piling-up of the eruptive material. The Absarokas are hemmed in, both to the north and to the south, by high ranges with approximately east and west trends. On the north are the Beartooth Mountains, presenting a broad elevated Archean mass culminating in some of the highest peaks to be found in Montana; while to the south are the Owl Mountains, consisting of an Archean nucleus capped and for the most part concealed by an arch of Paleozoic beds highly inclined along the outer edges. Between these two ranges lies a depressed basin, and resting unconformably upon the Archean are sediments of great thickness, derived in large part from the earlier continental areas.

These sediments, slowly deposited throughout a long period, represent nearly all the great divisions of Paleozoic and Mesozoic time. Beginning with the Cambrian, in their order of sequence, come the Silurian, Devonian, Trias, Jura and all the epochs of the Cretaceous recognized in Wyoming and Montana including the Dakota, Colorado, Montana and the Laramie standstone at the top, with its frequent fluctuations of sea level, foreshadowing changes in the development of the pre-existing continental area.

With the close of the Laramie sandstone the long-continued deposition of Mesozoic and Paleozoic sediments finally came to an end. In this region unconformity of sediments by deposition has not as yet been recognized, and in this sense alone they may be said to be conformable from Middle Cambrian time to the summit of the Laramie. Stupendous orogenic movements took place, and the surrounding country became one of mountain building on a grand scale, accompanied by plication, folding and faulting. The evidence all points in one direction—that this uplifting was contemporaneous in all the ranges of the northern Rocky Mountains. For this reason, and owing to its great geological significance, being one of the most important in Rocky Mountain geological history, the uplifting has been designated as the post-Laramie movement.

Along the west side of the Absarokas, and lying within the Yellowstone Park, extend north and south ridges of faulted and crumbled strata consisting mainly of highly inclined Cretaceous sandstone, the Laramie, nearly 10,000 feet above present sea level. From this ridge region eastward for fifty miles stretches this broad volcanic mass, finally dying out upon the plain over which the earliest lavas spread, resting on horizontal sandstones at an elevation of about 6,000 feet above sea level. After a very considerable erosion of the uplifted Mesozoic continental land area began the earliest of these volcanic eruptions, which later displayed such marvelous energy over this entire region of country, and which were closely related to the post-Laramie movement. This eruptive material, forcing its way upward, followed lines of least resistance along or near planes of faulting, or wherever the strain had been greatest upon the weakened strata.

The Absaroka Range was formed by the piling-up of successive accumulations of volcanic ejectamenta, with occasional interbedded flows of lava, burying everything beneath them to a depth of several thousand feet. Volcanic breccias, agglomerates and extrusive lavas, or those that have been poured out and cooled near the surface, constitute the bulk of the mountains.

These breccias and lavas were ejected from numerous fissures, vents and centers of explosive energy. Infinite detail as regards mineral composition and texture, and great complexity in mode of occurrence, may be observed. Viewed in a broad way and reduced to its simplest terms, the Absaroka Range consists of an uplifted volcanic region, presenting from one end to the other great uniformity, and even simplicity, in its main geological features. It is essentially a dissected plateau, deeply trenched by incisive gorges, offering exposures varying from 2,000 to 5,000 feet of nearly horizontal or only slightly inclined lavas. To this there are, of course, some exceptions, as is natural in any volcanic region. Notwithstanding the varied and complex manifestations of the eruptive breccias from many sources of outflow, this entire body of extrusive material has been divided broadly into six epochs, based upon their relative age and general sequence of lavas. They represent, in the geological history of the mountains, as many distinct phases of volcanic eruption. Beginning with the earliest in the order of eruption, they have been designated as follows: early acid breccia, early basic breccia, early basalt sheets, late acid breccia, late basic breccia, late basalt sheets.

Briefly stated, the interpretation of this history, as I understand it, is somewhat as follows:

So far as is known, the oldest volcanic rocks recognized in the Absarokas consist of a series of eruptives made up almost entirely of fragmental material, usually light in color, varying from grayish white to purple. In mineral composition they range from hornblende-andesite to hornblende-mica-andesite. Some of the siliceous varieties have developed phenocrysts of quartz in sufficient amount to be classed as dacites. These breccias appear to have been thrown out with violent explosive action from numerous centers, but from none of them was any large amount of material piled up; at least if it was thrown out it was subsequently worn down by atmospheric agencies. In no instance do they attain great elevation, the exposures being due to extensive erosion and deep trenching of narrow canyons. They are known only in the northern end of the range, and there in limited area, being buried beneath vast accumulations of still later material. These centers appear to be independent of later eruptions.

Overlying these acid breccias is a vast amount of volcanic ejectamenta, with here and there interbedded basaltic flows, the entire body having accumulated in many places to a height of several thousand feet. They occur far more widely distributed over the mountains than any other group of breccias, stretching both in its length and breadth from one end of the range to the other. They constitute nearly all the northern portion of the Absarokas, as well as the northeast corner of the Park. Unlike the early acid breccia, they are usually dark colored, owing to the amount of ferro-magnesian minerals present. The material consists largely of hornblende-pyroxene-andesite, proxene-andesite and basalt. Constant modifications and transitions occur, but over the entire area the prevailing rock is pyroxene-andesite, passing into slightly less basic rocks carrying hornblende on the one hand and into basaltic forms on the other. By far the greatest portion of this eruptive material is formed of coarse agglomerates, sombre in color, held together by varying amounts of cementing ash and silts of similar composition. The prevailing colors are black and brownish gray, while the finer silts and mud flows free from large bowlders are light brown, in strong contrast to the mass of the breccia.

It is difficult to describe in few words such volumes of volcanic material scattered

over broad fields and thrown out under varying conditions. Frequently these basic breccias present a rough and ropy surface, like ordinrry scoria irregularly heaped together, but the bulk of it indicates indistinct bedding. A tumultuous heaping-up of agglomerate by explosive action characterizes this breccia, which not infrequently carries andesitic and basaltic bowlders measuring 5 and 6 feet in length and often double that size. In one or two localities huge bowlders of crystalline gneisses and schists are also embedded in the lavas.

Scattered over the area occur the thin interbedded flows, apparently poured forth from numerous fissures and vents. These flows increased in frequency and thickness until finally massive outflows of basalt covered a considerable portion of the earlier series of breccias. Over how large a field they at one time may have extended cannot now be told, erosion having certainly removed them from large tracts, but they may never have been spread over extensive regions. It is somewhat curious that this continuous broad field of basalt has a northwest-and-southeast trend and stretches obliquely across the summit of the range from Mirror Plateau to Needle Mountain, whereas the body of the breccia in general has a north-and-south trend. The basalts lie upon the uneven surfaces of the breccia and occur piled up in a succession of flows, which in places near their sources have attained an aggregate thickness of 1,500 feet, although over large areas they measure about 1,000 feet, thinning out to a few hundred, while in certain places they appear to be wanting. Individual sheets range in thickness from 5 to 50 feet without showing any material change in the physical characters of successive flows. The greatest accumulation of flows appears to be along the trend of the basaltic body, thinning out both to the northeast and to the southwest, indicating that the eruptions had followed a fissure or system of fissures. Of course, this can be said only in a general way, as basaltic outflows may occur anywhere along the range. As regards mineral composition, they are usually fine grained, with but few well-developed megascopic constituents, mainly augite, olivine and plagioclase. In chemical composition they show within restricted limits considerable variation, with accompanying changes in mineral development, analyses determining a large amount of the alkalies and a correspondingly low percentage of silica. Numbers of these flows have built up, from vents, rounded bosses of basaltic rocks characterized by a development of orthoclase, in several instances associated with leucite. They are the extrusive equivalents of intrusive rocks, designated as absarokites in distinction from normal basalts. Reference will be made to them later, in speaking of certain intrusive masses. So far as our present knowledge goes, they belong chiefly to this period of eruptions. Many of these individual sheets stretch out for long distances, but others show great lack of continuity, thinning and thickening in different directions and often overlapping one another, indicating numerous sources of eruption and varying force and duration of flows.

In their topograpic configuration the basalts stand out in marked contrast to the loosely compacted breccias, owing to great uniformity of flows and to differences in weathering. To these basalts the name early basalt sheets has been given, and they are here treated as a geological unit, since they mark a distinct period in the history of volcanic eruption. It is quite possible, and even probable, that they covered this entire region and were subsequently removed by erosion, but of this there is no direct evidence. If they did, the country must at one time have presented a gloomy, sombre field of basalt, poured forth in a molten condition after a long period of fragmental

eruptions. How long the basalt period lasted cannot now be told. In determining the sequence of lavas these early basalt fields play an important part, as they overlie the early series of acid and basic breccias and underlie a somewhat similar series of eruptive material designated late acid breccia and late basic breccia and flows.

Following the basalts come the late acid breccias. They occur less widely distributed than the early acid breccias, and for the most part lie within the Yellowstone Park. Unlike the earlier breccias, they are less deeply buried beneath later eruptive material, but are piled up in successive layers one upon another, forming the summits of several prominent peaks and broad, plateau-like ridges. Over considerable areas they lie spread out in thin sheets over the basalt flows. Their centers of eruption occupy a restricted area and seem to be in every way quite independent of the earlier breccias and basalts. In mineral composition they closely resemble the early acid breccias, consisting of hornblende-andesite and hornblende-mica-andesite, in places mingled with a good deal of pyroxene-andesite, both augite and hypersthene being recognized, sometimes one and sometimes the other predominating. Much of the brecciated material is similar in mineral composition to the Ishawooa intrusive bodies, which will be discussed later. Nearly all of this material is fragmental, and the greater part of it is made up of coarse and fine tuffs. Frequently the contact between the light-colored acid breccia and the still later basic breccia is sharply drawn, the latter filling up depressions and levelling the accidented surfaces of the former, which occur at varying altitudes. In most instances the line of demarcation is not so sharply drawn, and not infrequently there is a mingling of material, as if there had been a pouring-out of the later rock before the complete cessation and closing-up of the more acid centers of eruption. Occasionally these light-colored rocks, from what appear to be local centers, lie directly upon basic breccia made up of basaltic bowlders and cementing tuffs of the earlier series, without the intervening basalts. Overlying these acid breccias there poured forth from numerous vents a second great volume of basic rocks and agglomerates, 2,000 to 3,000 feet in thickness, bearing a close resemblance to the earlier basic rocks. They are found over the southern portion of the Absarokas, usually resting upon the basalts, the late acid breccias being, as before mentioned, restricted to a limited region of country. Indeed, the second series of breccias forms the top of nearly all the high plateaus and the summits of the more prominent points. Cross-sections exposed in deep canyons reveal grand escarpments of both breccias, with intervening monotonous sheets of basalts. Viewed in a broad way, these two series of breccias are singularly alike, and apparently the conditions governing their eruptions were much the same. If we are to draw any distinctions, it may be said that the early breccias are apt to be scoraceous and slaggy and more chaotic in their tumultuous accumulation. The later breccia is more regular and distinctly bedded, and is almost wholly made up of both coarse and fine fragmental material, carrying large bowlders that could not have been thrown a great distance from the discharging vents. Bowlders weighing a ton or more are by no means uncommon. In general, it may be said of these later breccias that the coarsest material lies near the present crest of the range, and is seen to grow finer and more uniform, with distinct bedding, as one travels either east or west. To this rule, however, there are marked exceptions.

Following the late basic breccia, basalt tables are found here and there capping the

crest of the main ridge along the southern portion of the range. Probably they are all remnants of one continuous flow. They are best observed when seen eastward from Mountain Basin, when they present a castellated appearance, capping the coarser and lighter-colored rocks. In general habit they resemble the earlier basalt sheets, and, except for their position, have little to distinguish them from other similar flows. The part they play in the present configuration of the plateau is insignificant. The interest lies in the fact that these basalts complete a second cycle of eruption, which built up the Absarokas by the accumulation of successive flows of extrusive lavas, and that with them, so far as we have any positive record, the last phase of a long-continued series of eruptions came to a close.

That the piling-up of this eruptive material lasted through a long period of time is clearly established. In the first place, the early acid breccias show evidences of considerable denudation before the pouring-out of later lavas which now occupy the eroded areas. Not infrequently depressions may be seen filled with water-laid silts and fine gravels, which were afterwards covered by fresh outflows of breccia. Similar water-laid deposits may be observed in all the breccias, but they especially characterize the early basic series along the east side of the range, where the former existence of large lakes and ponds is manifest, with sediments of volcanic material over 200 feet in thickness deposited in comparatively quiet waters. In certain localities the basalts appear to be the result of fitful discharge and slow building-up from numerous vents. The thinning and thickening of beds in various directions, the overlapping of thin beds from different centers, and the frequently chilled surfaces of vesicular basalt, all point to a slow accumulation of the ejected lava. Occasionally in basaltic cliffs between lava sheets may be seen thin beds of volcanic sands and gravels, windstrewn over an exposed surface before being buried beneath fresh flows. Nowhere were interbedded layers of clay or earthy beds of decomposed rock observed, but such deposits are, I think, exceptional in most basalt areas.

While the gradual building-up of the plateaus from fresh accumulation was steadily in progress, erosion was constantly at work upon the surface; and, although volcanic fires ceased long ago, erosion has been going on steadily ever since. One of the most remarkable and puzzling features of the country are the areas of undoubted water-worn volcanic material, with its smooth and polished bowlders. Accumulations through floods and freshets abound; and, besides the evidence of ancient lakes and ponds found dotted over the surface, there are strong grounds for the belief that upon the upland existed broad rivers which carried the water-laid material across the plateau to the plain below. All this required a long time for its accomplishment.

Turning now to the land vegetation, convincing arguments are found not only for determining the age of the rocks, but for demonstrating that the eruptions lasted throughout a long continued period of activity. It is doubtful if any other known region in the world offers such a promising field of research, showing the relationship between plant life and volcanic eruptions, as is to be found in the Absarokas. In solving these problems the geologist is greatly indebted to the paleobotanist. From time to time extensive collections of fossil plants have been made, indicating a rich and varied flora. Portions of the region have been visited by our distinguished fellow members, Professor L. F. Ward and Professor F. H. Knowlton. All of the collections have been referred to Professor Knowlton, who has made an exhaustive

study of the material, and his researches are now in press. For specific determinations of these plants I refer you to his monograph. Already over 150 species of plants have been identified.

The early acid breccias have yielded a terrestrial vegetation regarded as of earlier age than that obtained from the superimposed lavas. It has furnished a grouping of species so closely allied to the flora found in the Fort Union beds, near the junction of the Yellowstone and Missouri Rivers, that the two floras are regarded as identical in age, and consequently referred to the Eocene period. From these acid breccias eighty species have been identified, and twelve of them were previously only known as belonging to the Fort Union horizon. Still others are common to both localities, but are found elsewhere as well. About one-half of the species are new to science, but according to Professor Knowlton their biological affinities relate them closely to the Fort Union flora. A second grouping of fossil plants, designated for convenience the intermediate flora, flourished at a time when the early acid breccia had about ceased to be emitted; at least they occur near the base of the lower basic breccia in beds indicating a mingling of both types of rock. In all probability they represent a flora which flourished in quiescent times, during a transition period from one series of eruptions to another, but foreshadowing a period of basic eruptions. This flora is of the highest geological significance, since it indicates a great duration of volcanic activity, with a change of climatic and physical conditions. This intermediate flora embraces about thirty species, of which only two or three are as yet known in the acid breccias. About the same number have been recognized as common to the basic breccias, but the evident affinities of the grouping are such that the flora as a whole is apparently more closely allied to the overlying than to the underlying rocks. For this reason it is referred to the base of the Miocene period and is regarded as older than the flora of the auriferous gravels of California.

The vegetation which flourished during the period of the basic breccias was, like the breccias themselves, widely distributed over the mountains wherever mud and silts were present to furnish a suitable soil. Nowhere can it be better studied than at the fossil forest of Specimen Ridge, in the Yellowstone Park, first explored by Professor W. H. Holmes over twenty-five years ago. Since that time other localities have been discovered, and quite recently beds holding leaf impressions of a similar flora have been found on the east side of the mountains. At the fossil forest precipitous walls expose nearly 2,000 feet of horizontal beds of breccias, silts and mud flows, in part laid down by floods and freshets and in part deposited by quiet waters. From base to summit at frequent intervals a terrestrial vegetation has sprung up and flourished, only in turn to be destroyed by renewed lava streams. In one of these buried forests a stump of a still-standing coniferous tree measures 10 feet in diameter and is surrounded by many fallen logs long since preserved by silicification. If one considers the length of time it takes for any vegetation to spring up on an arid lava field and the great age of many of these trees, the time necessary to build up a series of such forests one above another can hardly be overestimated. That there were long periods of rest between the outpourings of the lava seems evident. Throughout this 2,000 feet of erupted material it has been found impossible as yet to discriminate between vegetation found at the base of the cliffs and that interbedded with the lavas at the summit. This implies similar climatic conditions during the time demanded to renew and develop a varied flora between

successive layers of tuffs and muds. It may be well to state that all this probably took place before the period of basalt eruptions. This flora has yielded seventy species, and is regarded as markedly different from that of the earlier breccia, and of later age. As a grouping it shows the closest affinity to the auriferous gravels of California, many of the species being identical, while still others have the closest resemblance to species found only in the gravels. It has been named the Lamar flora, and referred, like the auriferous gravels, to the upper Miocene period. Both the late acid and the late basic breccias have recently yielded well-preserved leaf impressions, proving the existence of a more or less luxuriant flora in all the great periods of breccia eruptions. Such fragmentary material as has been found in these later rocks agrees with plants preserved in the early breccia at Fossil Forest, and, therefore, has been correlated with the Lamar flora of upper Miocene age. It was a vegetation essentially characterized by deciduous foliage. Several species of magnolias, aralias and other equally important groups which are marked features of the auriferous gravels flourished on these volcanic slopes. Specimens of *Aralia notata* occur widely distributed, and the leaves of some of them are supposed to have measured 3 feet in length by 2 in breadth. Associated with them are leaves provisionally referred to the genus *Artocarpus*, indicating the presence of the breadfruit tree. According to Professor Knowlton, this flora is extra-tropical and may be compared in many ways to the vegetation as seen to-day in southern Mississippi and the Gulf coast. He says: "It is obvious that the present flora of the Yellowstone National Park has comparatively little relation to the Tertiary flora and cannot be considered as a descendant of it. It is also clear that the climatic conditions must have greatly changed. The Tertiary flora appears to have originated, or at least to have had its affinities, at the south, while the present flora is evidently of northern origin."

On the slopes of Overlook Mountain, in the center of the range, nearly 11,000 feet above the present sea level, occurs a prostrate log, preserved by silicification, measuring 2 feet in diameter at its base. Not far distant other logs are found, and in the silts occur impressions of deciduous leaves. From this locality four species of plants have been determined as identical with species found in the fossil forest, among them an *Aralia notata*.

In a personal communication Professor Ward informs me that in his opinion the flora of this region grew virtually at sea level. While I recognize his eminent authority in such matters, I am hardly prepared to accept such a radical view, but I cordially welcome this expression of opinion because it in a measure corroborates my own belief that the silts and ashes on which the flora of Overlook Mountain flourished were laid down at a much lower level than that at which they are now found.

Briefly summarizing the facts brought out by a study of the fossil flora and their bearing upon the geology, it is, I think, indisputable that the flora affords abundant evidence of a great range of Tertiary time during the period of volcanic eruptions, even if geologists do hesitate to accept the precise determinations of the age of the different floras and their geological sequence. This luxuriant terrestrial vegetation, developed through thousands of feet of lava beds, tends to confirm the view that the accumulation of this erupted material was an exceedingly slow process. Again, the character of the vegetation lends a forcible argument to the belief that the entire region must have been elevated since the development of so varied an extra-tropical vegetation. For my part, I desire to pay tribute

to the great value of the fossil flora as an aid in deciphering the geological history of the Absarokas. Its interest and importance cannot be overestimated.

Only brief allusions have been made as yet to the intrusive bodies, although they play a most important part in the building-up of the Absarokas. Although such bodies in the form of dikes probably cut the breccias from time to time, it is clearly evident that all the large intrusions, together with the greater part of the dikes, were forced upward and into the breccias at two well-defined periods of eruption. The first of these periods was in part contemporaneous with the early basalt flows, and in part followed them. The second followed the late basic breccia and basalts, and, so far as can be told, completed the final chapter in the geological history of the immediate region. It is possible that later eruptions took place and that the material ejected was removed by erosion, but of this there is no positive record other than a few isolated patches of rhyolite which do not bear directly upon the problems before us and which may be regarded as outliers of the rhyolite of the Park plateau. It does not follow that the intrusions of either period were contemporaneous in age, but simply that they belong to a certain phase of the eruptive energy. Dikes may cut an earlier series of intrusives, and subsequently other dikes may intersect those which preceded them.

For the purpose of clearly discriminating between these two groups of rocks, the one that followed the early basic breccia has been named the Sunlight intrusives, from their remarkable exposures along Sunlight Creek and valley, while the later group has been named the Ishawooa intrusives, from the canyon of that name, where the complexity of their occurrences forms one of the most striking features of that impressive gorge. In mineral composition the Sunlight intrusives range from a quartz-augite-andesite, through transition forms of syenite and diorite, to orthoclase-gabbro. The large body at the head of Sunlight Creek is mainly a syenite with associated monzonites and diorites. On Closed Creek, in Crandall Basin, the intrusive body consists for the most part of orthoclase, gabbro and diorite. The series as a whole shows an association of the minerals augite, plagioclase and orthoclase, with quartz and biotite in its more siliceous members, and olivine and hypersthene in its basic members. In general, the Sunlight intrusives are more diversified in chemical composition than those of the Ishawooa group. The latter are more siliceous, carrying less of magnesia and alkalies, and the coarsely crystalline masses are much more like normal diorite, diorite-porphyry, granite, granite-porphyry and andesite-porphyry.

Of the Sunlight intrusive bodies the one situated near the source of Sunlight Creek, in the central portion of the range, is the most impressive, and at the same time the most typical in its occurrence. It measures nearly 3 miles in length and occupies the basins of all the deep glacial amphitheatres on the north side of Stinkingwater River, while all the high intervening ridges separating the basins consist of indurated breccia. Similar rocks are exposed in the Silvertip Basin, on the south side of the peak, and in all probability they form part of one continuous body.

The Crandall Basin stock, under Hurricane Mesa, exposed by the erosion of Closed Creek, has far less lateral expansion, but rises for nearly 3,000 feet above its base. Dikes radiate from all the large intrusive bodies, but nowhere else is their number so great and the part they play so strongly marked as in the region of the Sunlight stock. These dikes are by no means all connected with the large stocks seen at the surface, but may be observed in

great force at a number of localities in the early breccia along the east side of the range, far removed from any recognized crystalline body. Wherever these early breccias occur dikes are apt to be a marked feature of the country, in contradistinction to the country occupied by the latter breccias.

These dikes consist mainly of orthoclase basalts, which Professor Iddings, from his microscopical studies, has divided into absarokites, shoshonites and banakites, depending upon their varying mineral and chemical composition. In the field it seems impossible as yet to differentiate between them, and so far as can be told they present the same mode of occurrence. For most geological purposes they may be grouped together under the general term of absarokites. They form a connecting link between many of the eruptions in the early basalt sheets and the Sunlight intrusives. They are closely related to the syenites and monzonites of the Sunlight intrusive stock. Both these dikes and sheets occur over extensive areas.

Leaving for the present the Sunlight intrusives, let us take up the Ishawooa intrusives, which I select in order the more easily to bring out in detail certain facts bearing upon the origin of both types of intrusive rocks. Of the many intrusive bodies, Needle Mountain, in the southern end of the Absarokas, is the most imposing and instructive of them all. At the base runs the Shoshone River, through one of the most rugged and picturesque canyons to be found in northern Wyoming. This great stock, which stretches along the valley for nearly four miles, rises abruptly 4,000 feet above the stream bed, from an elevation of 7,000 feet above sea level. It is overlain by 1,000 feet of partially indurated and metamorphosed breccia. From the rounded summit of this commanding peak the breccias may be seen stretching far to the west on the opposite canyon wall, thence across Thoroughfare Plateau and on to the higher regions of Wind River Plateau, where they lie nearly horizontal at an elevation approximately the same as that of Needle Mountain itself. Upon this latter plateau the Shoshone River finds its sources, and in its rapid descent of 5,000 feet before reaching Needle Mountain exposes large, irregular stocks of indefinite outline piercing the breccias.

Looking eastward from Needle Mountain, the breccias extend as far as the eye can reach in the direction of the broad, open plain beyond. The massive stock of Needle Mountain consists essentially of diorite, quartz-diorite and diorite-porphyry, cut by numerous narrow dikes of apparently differentiated products of the same molten magma. Offshoots and apophyses from the parent stock pierce the surrounding breccia, and a number of small dikes penetrate the overlying breccia. From these dikes sheets of granite-porphyry stretch out into the breccias, and on the spurs of the mountain erosion has worn them bare, leaving them exposed as the surface rock. The stock is found on the opposite side of the canyon, rising high above the stream and capped by the ever-present breccia. Bordering the diorite stock the breccias are indurated, crushed, and so altered that not infrequently it is impossible to discriminate between breccias and intrusive stocks without the aid of the microscope. Dr. Jaggar has shown that many of these fine-grained rocks are altered mud and silts and metamorphosed breccias.

From Needle Mountain to Mount Chittenden, in the Yellowstone Park, a distance of over fifty miles, there extends in a northwest direction a remarkable and probably a continuous belt of intrusive rocks. These intrusive bodies occur as stocks, sheets, bosses and dikes, varying from irregular-shaped masses of stupen-

dous proportions, two and three miles in width and several thousand feet in height, to narrow dikes and seams traceable along the canyon walls for only a few feet and often disconnected at the surface from any other body. A short distance north of Needle Mountain, but on the opposite side of the canyon, another great stock rises precipitously above the stream bed, and it is clearly evident that its relation to the breccias are in every way similar to those observed at Needle Mountain. Between these two massive bodies smaller outcrops of diorite and diorite-porphyry are exposed in lateral ravines on the mountain sides, and the network of dikes trending in every direction points conclusively to the fact that these intrusive bodies belong to one and the same stock. Dislocated and indurated bodies of breccia are found upon the mountain spurs, but the overlying capping of breccia peacefully crowns it all.

From this point northward, following along the line of the powerful intrusions, each dissecting canyon, where it cuts the intrusive masses, lays bare numerous exposures of crystalline rocks which have forced their way upward into the breccias, and, following lines of least resistance, have spread out in all directions with a marvelous complexity of form and outline. Some of the stocks penetrating the breccia have attained elevations slightly above the present level of the plateau, but most of them failed to reach so high a position. Wherever they have reached the top of the plateau their tendency is to spread out in sheets, which now form the exposed surface of spurs and ridges. Many of these interbedded sheets are directly connected with some of the larger stocks, but others show no such relationship at the surface and stand out quite independently of them. Occasionally the sheets bulge up with irregular outline; others are dome-shaped, developing laccolithic form. Vertical dikes cutting the interbedded breccias pass into sheets, and later again assume the conditions of normal vertical dikes. The variable character of the breccia, sometimes compact and uniform and at others made up of an incoherent mass of silts and ash, tends to constant change in the upward movement of the molten magma.

The gorges of both Cabin Creek and Canyon Creek expose similar rocks, with accompanying phenomena of strain and rupture. Ishawooa Canyon, one of the most rugged of these incisive trenches, presents varied modifications of eruptive energy, a bold stock, Clouds Home, piercing the breccias with an irregular outline from the bottom of the canyon to the top of the plateau. One of the finest examples of a massive interbedded sheet extends for a mile or more along the canyon wall. Similar phenomena present themselves in Wapiti Canyon, where four tributary streams, uniting to make the river, have cut down in the intrusive masses in a most instructive manner. Near the sources of Eagle Creek diorite and andesite-porphyry are again laid bare, and thence, trending across the crest of the range, extend as far as Sylvan Pass, where coarsely crystalline diorite and diorite-porphyries come to the surface for the last time in an exposure nearly a mile in length. Beyond this point eruptive energy gradually dies out, and is only shown by the presence of a few powerful dikes noticeable for their uniformity and persistency.

A distinctive feature along this entire line of intrusive rock is the belt of indurated breccia which accompanies it. Near the larger stocks the alteration of the breccia is especially noticeable, and not infrequently it is difficult to discriminate between the stock masses and the metamorphosed material. The mode of weathering is so unlike that of the ordinary breccia,

and the transitions are so gradual, that it is by no means easy to define the outlines of the intrusive masses without personal inspection. Although never having been followed as a continuous body, owing to the nature of the topography, the zone of induration is one of the marked features of the region, and under favorable conditions may be traced in the canyon walls for fifty miles, with a width in places of more than one-half mile. Another important and significant feature is the inclination of the breccias away from some well-defined axis or central ridge. They do not as a rule arch over any single powerful protrusion, but present every indication of a broad anticlinal structure, with the piled-up lavas inclined toward the west and southwest on one side and toward the east and northeast on the other. Between the more massive bodies that have been forced upward to elevations above the general level there may be found areas of indurated breccia, traversed by a labyrinth of dikes and veins in their efforts to force their way upward.

Without entering into petrographic details, a few words in addition to what has already been said seem necessary. Granites and diorites are seldom met with other than in connection with the large uniform stocks. As most of these stocks are only partially exposed, their volume can only be a matter of conjecture, but in all the larger bodies, such as Needle Mountain, the rock is essentially that of a medium-grained diorite or diorite-porphyry. A true granitic structure is by no means uncommon. Most of the powerful intrusions, as regards their crystalline structure, may be classed as granular. The great bulk of these crystalline rocks apparently carry some little groundmass. Porphyritic structure, with little groundmass, is a characteristic feature, with transitions into andesite-porphyry and andesite. Many similar bodies of indefinite outline, only partially exposed by erosion of the canyon walls, are andesites. Indeed, all the relatively small bodies are andesitic in habit, and the same is true of the many outlying bodies away from the general northwest-southeast trend of the intruded rocks.

A field study of these rocks of varying degrees of crystallization shows clearly that they were all exposed to virtually the same degree of pressure of overlying rock, and that their structural differences were not dependent primarily upon pressure from above. Many of these andesitic masses are much smaller than the diorite bodies and occur at much lower levels below the superimposed load. All observations upon the geological relations of these intrusives to the breccias tend to show that their structural differences are dependent far more upon the chilling effect of the surrounding rock and the rate of cooling than upon the pressure of the overlying rock. Geologists and petrographers have been for a long time investigating the structural differences and mineral variations of igneous rocks. Of these philosophical investigators Professor Iddings stands in the foremost rank. In an exhaustive petrographic study of the Crandall Basin intrusive body and its complex system of radial dikes of varying composition he reaches the conclusion that they have all been derived from the same parent molten magma, but crystallized under different conditions. With this conclusion I heartily agree. Dr. Jaggar, who has been at work upon a petrographical study of the intrusive rocks of the rest of the Absaroka Range, has reached a similar conclusion as regards the Ishawooa intrusive stock and associated sheets and dikes, and believes that they were derived from a common molten magma, which is quite in accord with geological observations in the field. From these observations, thus briefly and imperfectly stated, the conclusion seems inevitable that the Ishawooa intrusive, for its entire length of fifty

miles, represents a continuous ridge, the result of the consolidation of a molten magma intruded into the breccias. Erosion has as yet laid bare only the more elevated portions and some of the connecting links.

If a trained geologist were to stand on any one of the more prominent points in the Absarokas his attention would, first of all, be attracted by the vast amount of fragmental ejectamenta lying with apparent horizontality in every direction. Closer observation would impress him with the bedded nature of much of this material and the action which running water had played in disintegrating the lava and rounding the andesitic and basaltic bowlders. If, by chance, he had acquainted himself with the huge stocks exposed in the canyons, knowing the power of dense crystalline rocks to withstand atmospheric agencies better than the easily disintegrating breccias, he would be surprised to find that none of the larger ones towered above the plateau in commanding peaks. At one or two localities they attain the present level of the plateau, but do not rise much above it, and usually give evidence of the dying out of the energy which forced the magma upward. As these intrusive stocks are overlain by breccia sometimes 1,000 feet in thickness, it is difficult to see how they ever could have been centers of powerful extrusive eruption.

In an address delivered before the British Association for the Advancement of Science in September, 1893, Professor Iddings took the ground that the Crandall Basin stock was the core of a grand volcano, from which issued the breccias, silts and tuffs which have built up the north end of the range, while the gabbros and diorites represent the coarsely crystalline development of that portion of the magma which cooled at great depths beneath the surface. He reconstructed a volcano to a height of 10,000 feet above the plateau, and subsequently removed by erosion every vestige of the volcano down to the summit of Hurricane Mesa, the present level of the plateau. He likens it, in magnitude and in the processes by which it was built up, to the volcanoes of Ætna and Vesuvius. An abstract of the address was published in the *Journal of Geology* for September and October, 1893, and in a forthcoming report on the geology of the Yellowstone National Park a detailed description of the Crandall stock will be found, together with the results of his admirable petrographic studies of the rocks, to which allusion has already been made. After what has been said, it seems hardly necessary to add that with these geological views of Professor Iddlings I do not agree. My interpretation of the history of this region may possibly call forth the friendly criticism that this address is an account of the early Tertiary volcanoes of the Absarokas with the volcanoes left out. For such criticism there may be some slight ground; but, while I fail to see any evidence of the building-up of such volcanic piles as Vesuvius and Ætna, or, as I should prefer to put it, volcanoes of the type of Rainier, Hood or Shasta, there was displayed intense explosive energy accompanied by immense volumes of steam and the piling-up of a vast block of lavas from many centers of activity. Instances of such explosive energy may be seen at Chaos Mountain, but the material thrown out yielded readily to atmospheric agencies and soon became spread out over the entire region. The whole area of the late acid breccia suggests several powerful vents for the ejectment of fragmental material and the partial wearing-away of mounds and ridges of the heaped-up accumulations. It is possible that before the Sunlight and Ishawooa intrusives were forced upward volcanoes existed, but that any one or two of them dominated the region and influenced the topographical configuration of the Absarokas is exceedingly doubtful. There is noth-

ing to indicate the characteristic slopes of a great volcano.

Within the Yellowstone Park and just west of the Absarokas occurs a fine example of a volcano, situated near the intersection of the prolongation of the Ishawooa intrusive body and the fault along the southern slope of the Snowy Range. Mount Washburne is the culminating point of the volcano, which consists almost wholly of fragmental early basic breccia. From a well-recognized crater, since partially filled with rhyolite, the erupted material has been thrown out in every direction, building up true volcanic slopes encircling a central discharging vent. Such a structure I have never been able to recognize in the Absarokas. Mount Sheridan, in the Park, is another large volcano, but this is a Pliocene eruption consisting wholly of rhyolite, and is one of the sources of the great body of rhyolite which built up the Park plateau probably long after the Absarokas ceased to be a center of volcanic action.

Of all known regions of eruptive energy within historical times, Iceland in many ways affords the best field for comparison of the volcanic phenomena of to-day with conditions as they existed during the early Tertiary time in the Absarokas. Iceland is one of the active centers of eruption on a stupendous scale. It offers a continuous volcanic history throughout Pleistocene time, and dates back to the early Miocene, as is indicated by its fossil flora. In early Tertiary time the island was a region of profound faulting, and it is supposed to have been separated from the mainland during that period. Dr. Thoroddsen, the Icelandic geologist, has published in European scientific journals most interesting accounts of his explorations over the less-known regions of the island. The most complete and instructive of these accounts which has come to my attention was published by the Stockholm Society of Science in 1888. Notwithstanding the volcanoes of majestic proportions which contribute so much to the scenic grandeur of Iceland, and which must give to all geologists who have seen them a profound sense of the power of volcanic energy, Dr. Thoroddsen, who has lived among them, protests against the idea that they were built up like Vesuvius or Ætna. He says: "The vast lava waste of Odadahraun was produced by the eruption of over twenty volcanoes, and perhaps many of the oldest centers of eruption that contributed to the formation of this desert have become obliterated by later lava streams. When one recalls geological text-book descriptions of modern volcanoes and their activity, it is nearly always Vesuvius that everywhere turns up like a spectre, whereas the regular volcanic cone composed of alternating lavas and tuffs is rather rare in Iceland."

The country which he is describing may be about one-half the size of the Absaroka Range, but I have no maps or accurate data for determining the area. Again, later, he says: "Only a few old volcanoes are found having this form. In Iceland it is very generally found that the fissure has not given rise to the formation of any real volcano. The lava there has sometimes welled out along the entire length of the fissure without the formation of a crater, but mostly there has been formed a series of low slag cones at the points where the magna, by reason of the form of the fissure or for some other cause, found it easiest to break forth. Such rows of craters are found in all volcanic regions of Iceland." Another noticeable feature, even in the active regions of Iceland, is the ease with which sources of eruption may become obliterated by fresh flows from neighboring vents of discharge. According to Dr. Thoroddsen the famous Heckla itself is a long ridge built up by a chain of small craters along a line of fissure.

Sir Archibald Geikie, in his admirable

work on the Ancient Volcanoes of Great Britain, in comparing the volcanic phenomena of the Icelandic eruptions with those exhibited by the basalt plateaus of the British Isles, remarks: "It is, therefore, to the Icelandic types of fissure eruption, and not to great central composite cones, like Vesuvius or Ætna, that we must look for the modern analogies that would best serve as commentary and explanation for the latest chapter in the long volcanic history of the British Isles."

In comparing volcanic areas of Iceland with the phenomena exhibited in the Absaroka Range there is one striking difference to be noted. In the former the extravasated molten magma consists largely of basaltic flows, while in the latter one is constantly impressed by the enormous amount of brecciated rock emitted. It is estimated that four-fifths of these extrusive rocks which make up the range consist of coarse and fine breccias, silts and related ejectamenta. Dead Indian Peak, one of the dominating points of the range, rises more than 6,000 feet above the valley, presenting layers of breccia which in the aggregate measure nearly one mile in thickness. It is a very conservative estimate to place the volume of breccia at one-half mile in thickness over the entire region under discussion, which, it should be remembered, embraces not much less than 4,000 square miles. This only allows for erosion an amount equal to the highest plateau summit, but it is sufficient to give one an idea of its vast bulk. That the denudation from the top of the existing plateau was very considerable is unquestioned, but there exist, I think, no reliable data upon which to base even an approximate estimate of the amount. Possibly the country was at one time covered with a mantle of basalt, which, withstanding erosion, would, of course, protect the friable volcanic material throughout a long period.

It is evident that the granular rocks required for their uniform crystallization an overlying load of greater or less depth. For my own part, I am more or less skeptical as to the need of an immense thickness of overlying material to develop such uniform consolidation as is generally supposed to be necessary to produce the so-called plutonic rocks. At Needle Mountain the medium-grained granular diorite for the entire 4,000 feet of rock face is apparently the same throughout, whereas only a short distance from the mass and at a lower level small bodies of rock in cooling have developed a characteristic andesitic structure.

It must be borne in mind that all this material, of varied mineral composition, grouped together under the designation of breccias, was congealed and crystallized before it was hurled out by explosive action. This means stupendous crushing and crunching of the mass as it was forced upward, and disturbances of the first magnitude, which must have had their origin in great crustal movements. Whence came this enormous mass of brecciated rock? Twice during the long period of their eruptions these breccias had been invaded by enormous bodies of granular rock which had elevated the entire Absaroka Range, an elevation that was phenomenal in its nature and formed a part of the great series of orogenic movement which uplifted the northern Cordillera. This uplift was closely related to the post-Laramie movement, which was one of the most profound and far-reaching orogenic disturbances anywhere recognized by geologists.

Throughout this address the large individual protrusions into the breccia have been alluded to as stocks, but I regard them as the more elevated portions of a great complex of crystalline rocks underlying at least a large part of this region of country. Where the underlying molten magma was subjected to the severest pres-

sure the material was squeezed upward to higher levels, following lines of least resistance, and consolidated at greater or less depths beneath the surface. This upward movement was probably coincident with the crustal movements that elevated the entire Absaroka Range. The line of Ishawooa intrusives marks the trend of one such upward movement of molten magma, which for the most part congealed without finding egress to the surface. That a portion of the magma may have been pushed upward through fissures and vents and discharged as surface flows of andesite is possible, but of such flows, if they existed, no positive evidence remains.

Conditions somewhat similar to those found in the Absarokas are described by Professor Adolph Stelzner as occurring in the Andes of Argentina. He describes granites, diorties and syenites as penetrating the andesitic tuffs and lavas of Tertiary age, and as cooling under a heavy load of superimposed material. He does not regard these massive crystalline bodies as conduits of volcanoes, but as large stocks formed independently of such vents. He refers to them as taking part in the great orogenic uplift which elevated the Cordillera of South America, an uplift which began in Jurassic time, lasted through the Mesozoic, and continued through the greater part of the Tertiary.

In the discussions of volcanic phenomena found throughout geological literature, circular vents of great depth seem to be regarded as indispensable and are supposed to furnish an open door for the molten magmas, permitting them to take a straight shoot from the eternal depths to daylight. In this way geologists certainly avoid many perplexing physical problems which confront us in the case of stocks and laccoliths penetrating sedimentary rocks and stopping far short of the surface. In speaking of areas of igneous rocks, one almost hesitates to use the term laccoliths, so universally is it referred to in its relation to sedimentary rocks. For my part, it seems far more reasonable to look for such intrusive bodies in areas of igneous rock than in regions of sedimentation. That large intrusive bodies came to a standstill without any surficial manifestations, in the Absarokas, is, I think, fairly well determined.

Two years ago it was my good fortune to cross the Cascade Range at a number of localities and to climb far above timber line the slopes of Mount Rainier, in Washington; Mount Hood, in Oregon, and Mount Shasta, in California. From these commanding points comprehensive panoramic views were obtained over a broad field of igneous rock. Majestic and impressive as are these volcanoes, and grand in their isolation, I could but feel that back of them all lay earlier chapters in the Tertiary history of volcanic energy on the Pacific side of the Cordillera; that these powerful volcanoes were but a late expression of the intensity of the eruptive energy, and that still earlier volcanic masses had in some way taken part in the orogenic disturbances of an earlier Tertiary time. So, on the east side of the great Cordillera, the early Tertiary fires long since ceased to glow in the Absarokas, and the center of volcanic energy moved westward and built up on different lines the broad rhyolite plateau of the Yellowstone Park, a plateau strongly contrasted with the Absarokas in the almost entire absence of breccias. The work of such investigators as Emmons and Cross in Colorado and Weed and Pirsson in Montana is slowly but surely solving the problems of the post-Cretaceous uplift in the northern Cordillera, and, it will, I think, finally be shown that the crystalline rocks consolidated below the surface have played an important part in bringing about the Cordilleran revolution.

On a bright crisp autumnal day in 1897 I left the Absarokas by the way of that

most interesting of valleys, Clark's Fork of the Yellowstone, still impressed with the many unsolved problems connected with the geology of the range. I at first visited the region in the expectation of finding a partially submerged range of Paleozoic and Mesozoic sediments. If ever such range existed, it had completely disappeared by profound subsidence. I then looked for the roots of some powerful dominating volcano which had been the source of the varying breccias, but this also I failed to discover. In its stead, if I interpret the facts correctly, I found penetrating the breccias the towering domes and pinnacles of granular and porphyritic rocks, which in some far-distant day, when denudation has removed a greater part of the overlying mass, may be found to form one connected body which erosion has already so far laid bare as to indicate that they all form a part of one broad complex of coarsely crystalline rock of early Tertiary age.

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THE PHYSIOLOGICAL BASIS OF MENTAL LIFE.*

IF we demand a physiological process corresponding to every possible variation of the content of consciousness the structure of the brain seems far too uniform to furnish a sufficient manifoldness of functions. The mere number of elements cannot be decisive; if they are all functionally coordinated they can offer merely the basis for coordinated psychical functions. If we have psychical functions of different orders it would not help us even if we had some millions more of the uniform elements. It would be useless to deny that here exists a great difficulty for our present psychology; the only question is whether this difficulty really opposes the demands and suppositions of psychophysical parallelism or whether it means that the usual theories of to-day are inadequate and must be improved. It seems to me that the latter is the case, and that hypotheses can be constructed by which all demands of psychology can be satisfied without the usual sacrifice of consistency. The situation is the following:

The whole scheme of the physiologists operates to-day in a manifoldness of two dimensions: they think the conscious phenomena as dependent upon brain excitements which can vary firstly with regard to their localities and secondly with regard to their quantitative amount. These two variations then correspond to the quality of the mental element and to its intensity. In the acoustical center, for instance, the different pitch of the tone sensations corresponds to locally different ganglion cells, the different intensities of the same tone sensation to the quantity of the excitement. Association fibers whose functions are not directly accompanied by conscious experiences connect these millions of psychophysical elementary centers in a way which is imagined on the model of the peripheral nerve. No serious attempt has been made to transcend this simple scheme. Certainly recent discussions have brought many propositions to replace the simple physiological association fiber which connects the psychophysical centers by more complicated systems—theories, for instance, in regard to the opening and closing of the connecting paths or in regard to special association centers or special mediating cell groups—but these and others stick to the old principle that the final psychophysical process corresponds to the strength and locality of a sensory stimulation or of its equivalent reproduction, whatever may have brought about and combined the excitements.

It is true that it has been sometimes suggested that the same ganglion cell may go

*Read before the joint meeting of the Psychological Association and the Physiological Society.